Using AUV's and Sources of Opportunity to Evaluate Acoustic Propagation

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LONG TERM GOALS

To develop a passive acoustic volume array for the AUV Ocean Explorer II which may be used to investigate different sources of sound in the coastal region. The system will be able to autonomously detect changes and variations in the near shore environment by measuring acoustic propagation from ambient noise and man-made sources. The system will also collect breaking waves noise directivity data to be correlated with turbulence measurements taken close to the sea surface.

OBJECTIVES

The objective of this research is to develop a fully functional payload for the AUV Ocean Explorer II to perform passive sonar measurements from a stationary platform. The system will be able to undertake missions which include multiple Landing/Measurement/Takeoff sequences, so that it can monitor ambient noise variations at many different locations. In a moored version the system will measure noise directivity over long periods of time to study the temporal variation of ambient noise in the coastal region. Finally, the payload will be used to track moving AUV's by measuring the directivity of modem signals emitted from the vehicles.

APPROACH

The approach followed in this research was as follows:

1. First it was necessary to finalize and complete the design of the Ambient Noise Sonar (ANS) payload for the OEx AUV developed at FAU by Dr. S. Smith, so that the vehicle could carry out multiple Landing/Measurement/Takeoff missions. Several issues had to be addressed in order to develop a vehicle that could land on the sea floor. A Variable Buoyancy System (VBS) module was designed and integrated into the payload. This VBS contains a standard diver buoyancy compensator that controls the displaced volume of the vehicle and allows it to change buoyancy from slightly positive to 38 lbs. heavy. The system was successfully integrated into the OEx II and fully tested.

2. During the development time the ANS was used as a stand-alone platform to perform measurement of ambient noise and modem tracking. The stand-alone payload was used during the Indian Rock Beach Experiment off Clearwater in February/March of 1998. Interesting results on the diurnal variations of ambient noise during a 17 hours period were obtained and are discussed below. In another experiment off the coast of Boca Raton, the ANS was able to track a moving vessel equipped with a

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PSK modem to demonstrate the ability of the ANS to track AUVs. The system also imaged bubble noise from a diver breathing apparatus.

WORK COMPLETED

1. The complete design for the ANS payload with a variable buoyancy system module was finalized in early January of 1998. However, the necessary modifications to the payload hardware and electronics could not be carried out until after the Indian Rock Beach experiment in March 1998.

2. In February/March 1998 the payload was deployed three times in the Gulf of Mexico during the Indian Rock Beach experiment to measure near shore ambient noise directivity, modem signals and noise from a moving storm front during an overnight mission. In this last mission the system was deployed for a period of ~42 hours and collected data non-stop for 17 hours. The results from these experiments are discussed in the next section.

3. The ANS payload is a modular system with four major components:

    (1) The ANS main pressure vessel that houses the ANS computer used to control the missions, the data acquisition, processing and storage. This vessel also houses the power management, A/D & DSP boards and the electronic relays used to control both the VBS air flow and the stepper motor used to open and close the retractable volume array.
    (2) The power section which includes the 8 battery ring and control box.
    (3) The Variable Buoyancy system that contains a 40 lb. bladder equipped with a 2 air tanks, a mechanical differential pressure valve and two solenoid valves used to control the air flow in and out of the bladder.
    (4) A retractable volume array that contains 5 arms of 1.5 m length placed 36 degrees apart, a 30 cm long arm raising mechanism with a central ball screw, and a stepper motor that rotates the screw. The hydrophones are fixed at the end of the arms (fig. 4,5).

The integration and automation of the payload into the AUV required several modifications and the addition of nodes in the ANS main can to connect the payload to the AUV LON (Local Network). The LON was integrated into the ANS to make the VBS available from both the ANS and AUV computer. A set of Matlab codes have been written to carry out the AUV missions and to allow exchange of information. This control software is used to manage the different functions of the ANS during a mission. At first the system is on stand by waiting for AUV commands indicating that the AUV has landed, while it monitors the system for leaks. Once the AUV has landed the ANS deploys the array. Once the data is collected the array is retracted. When it is fully retracted, a ready for takeoff status is sent to the AUV, which then takes over. The system goes to the next way point where the same protocol is repeated. The payload attached to the tail section was taken out for several simple tests to refine and set the VBS before the full final missions carried out in August 1998.

1. During the different phases of integration of the system into the AUV, the payload was used as a stand alone moored platform to perform several experiments. The system was used to measure signals from a FSK (Frequency Shift Key) and PSK (Phase Shift Key) modem mounted on a moving vessel in order to illustrate the ability of the ANS to track moving AUVs by measuring the directivity from the

modem signals. The experiments were carried out in February for the FSK and August 1998 for the PSK. The results for the PSK modem are shown in the next section.

2. Finally in September, the payload was dismantled and the components (1) and (2) as described above were placed into an aluminum structure with fixed arms to prepare for the mine counter measure and adverse weather experiments scheduled for November/December 1998. In this experiment the system will be moored to track AUV modems or to monitor the directivity from breaking waves.

RESULTS

1. The results obtained at Indian Rock Beach in February/March using the ANS payload are shown in this section. The system was used to measure global directivity of ambient noise. It was found that snapping shrimp accounted for most of the ambient noise in the absence of boat traffic. This was consistent with the data found in previous years off the East Coast of Florida. It was also found that the noise field was anisotropic due to the sparse distribution of the snapping shrimp colonies. During the adverse weather experiment in the night of March 6th to 7th 1998, very good biological noise directivity was collected. Figure 1 and 2 show the spectrogram of the ambient noise over a period of 17 hours, and corresponding horizontal directivity as a function of time. A strong correlation exists between the ambient noise spectrum and sunset and sunrise indicating the presence of biological choruses. The shrimp noise level in the band 2 to 8 kHz varies significantly with the sunset and sunrise, see figure 1. The direction of arrival of the shrimp noise is between the angles -180° to –120° pointing toward a distribution of stone crab traps and a rocky area in 8 meters of water SSW of the array (figure 2). The noise also comes between 10° to 100° in the NE direction pointing toward the beach and the nearby inlet (approx. 2 nautical miles). At sunset another stronger source appears centered around 1 kHz with energy up to 4.5 kHz in addition to the shrimp noise. This biological chorus lasts until around 01:00 AM. and it is attributed to the presence of moving schools of fish (croakers). The array was able to track the schools of fish as they move across the area. These results illustrate the ability of the ANS to study biological activity in the near shore region for long periods of time.
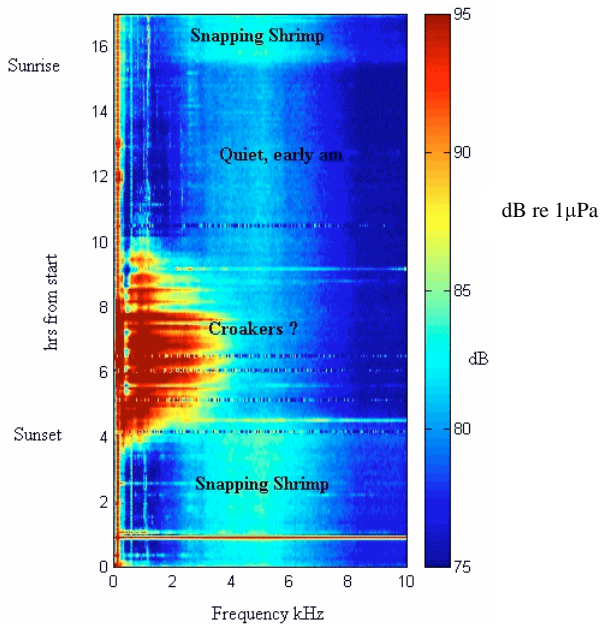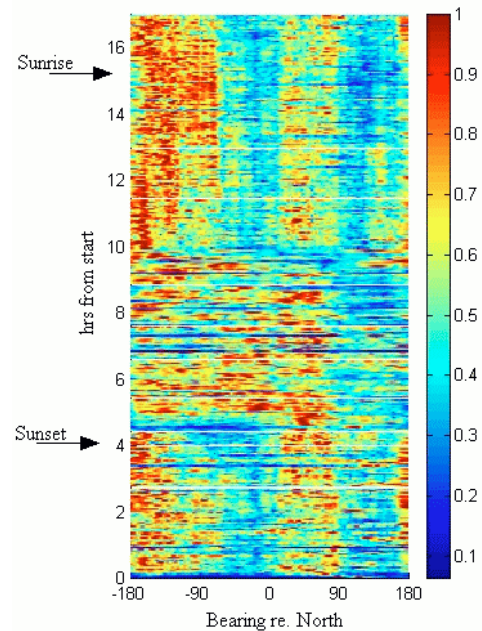

Figure 1: Spectrogram of Ambient Noise   *Figure 2: Normalized Directivity of Ambient Noise*

1. Multiple Landing/Measurement/Takeoff missions were carried out in July/August 1998.
   - Mission 1: July, 24 1998, Sea State: Moderate. Wave height 3 feet or less. Vehicle operating in 20 feet of water. In this mission the ANS was integrated into the AUV "Magellan". The vehicle took its first successful flight with the ANS payload, and it was determined that a minimum speed of 1/2 knots was required to keep control of the vehicle.
   - Mission 2: August, 14 1998, Sea State: Calm. Wave height 0.5 feet or less. Vehicle operating in 20 feet of water. After modifications to the VBS regulator the ANS was refitted to the AUV "Magellan", and the buoyancy tests were successful. The vehicle ran 5 successful Landing/Takeoff missions.
   - Mission 3: August, 20 1998, Sea State: Agitated. Wave height 4 feet or less. Vehicle operating in 20 feet of water. In this mission the vehicle would land, open arms, take data, retract the array and takeoff. The vehicle was launched successfully and ran the full mission twice. Video footage and photographs were collected. The sea state and wave height increased after mid day and it was decided that no more missions should be carried out for safe retrieval of the vehicle. In 20 foot depth the surge slightly rocked the vehicle. However, even with the arms fully open, it did not flip over and behaved well in the surge.

Figures 3 to 6 illustrate the different steps of the mission: The system runs a preset course and descends by increments to about 10 feet off the sea floor. Once it reaches its destination it coasts in the current for 10sec. In figure 3 the system lands on the sea floor after releasing all the air inside the bladder. Figure 4 shows the array opening. In figure 5 the system is collecting data, and in figure 6 after the bladder is filled until it is full and the system takes-off.
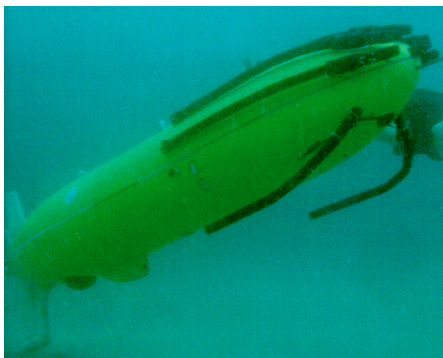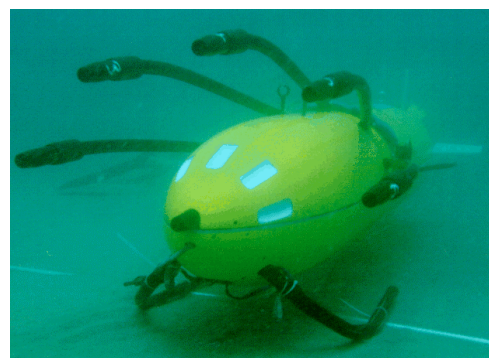

Figure 3: ANS Payload Landing on Sea Floor

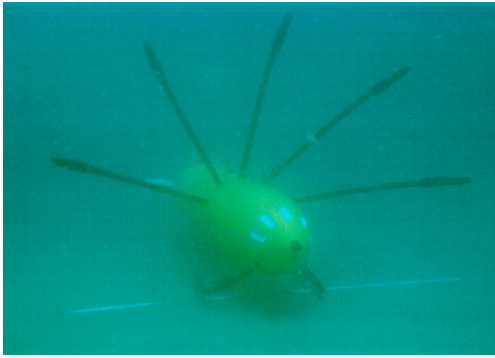*Figure 4: Volume Array Opening*

Figure 5: The ANS Collecting Data

Figure 6: System Taking-off

2. Figure 7 shows the results of the modem tracking experiment carried out in August 31, 1998, when a PSK modem from an AUV was mounted onto a moving vessel at ~200m range from the ANS. The track of the vessel was first to the East then to the North and back. In this figure the horizontal directivity against time indicates the path of the vessel and gives information on the heading and speed of the vehicle. Figure 7 is processed in the band 18-25 kHz.
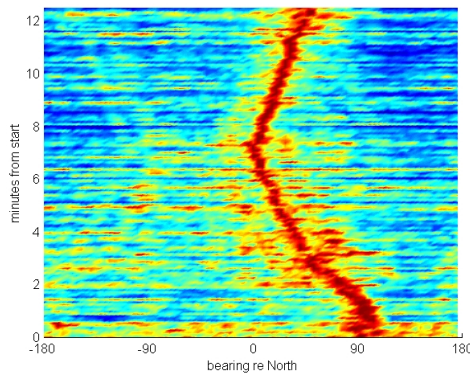

Figure 7: Modem tracking in the band 18-25 kHz

3. Figure 8 shows the results obtained with the ANS when measuring bubble noise from a diver breathing apparatus as it circles around the ANS at 10m range. The tracks of the diver can easily be seen as the bearing changes linearly with a slope proportional to the diver speed. The line of constant bearing indicates the presence of stationary biological noise. Figure 9 shows the bubble cluster and diver mouth piece. The processing was done from 0.1-5kHz. These two results show that the ANS can be used to image bubble noise and its potential use for measuring noise from breaking waves.
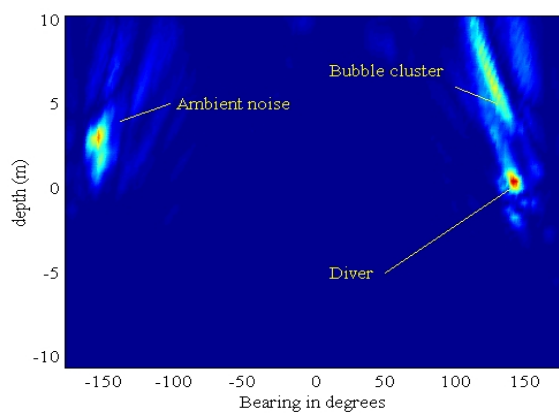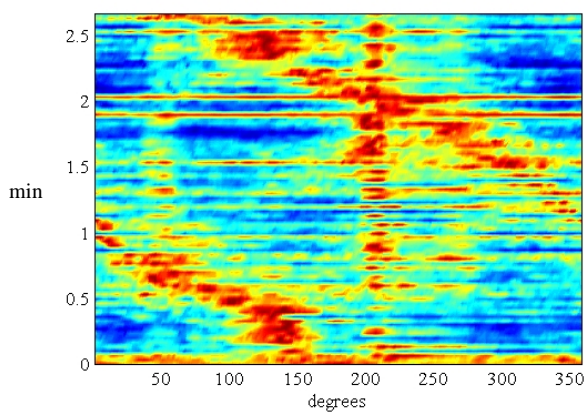
Figure 8: Diver Noise: Norm. Horiz. Directivity   *Figure 9: Imaging Ambient & Bubble Noise*

IMPACT/APPLICATIONS

The ANS has been successfully integrated into the AUV Ocean Explorer II and will be a useful sensor for passive survey and surveillance tasks in shallow water. The development of the VBS and the demonstration of the ability of a vehicle to land and takeoff has important implications for the developments of future sensors. There is now the possibility to integrate a VBS module into the design of new payloads to achieve more complete surveys using AUV's. The ANS ability to image noise sources, as various as boats, modems, bubbles and biological noise sources from below 1 and up to 25 kHz illustrates the potential applications of the system and the processing techniques. The next step is to use these directivity measurements to understand the mechanisms that cause changes in the near shore environment.

RELATED PROJECTS

Development of the OEx AUV vehicles at Florida Atlantic University (Dr. S. Smith).

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